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DIRECTORATE OF WEAPON RESEARCH (DEFENCE)

SURVEY OF COMPUTING FACILITIES IN THE U.K.

BY

C.A. REINERS. B.A.

SEPTEMBER 1953

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F O R E W O R D

This survey of the Computing Facilities in the United Kingdom has been prepared as the direct result of a directive from Sir Ben Lockspeiser, FRS., given when he was Chief Scientist in the Ministry of Supply; to his drive and foresight is due much of the present activity in computing affairs in the Ministry.

The object of this paper is to help departments and establishments who have computing problems which are beyond their own resources: to give guidance on the class of machine most suitable for a particular problem: to indicate where advice on or facilities for computation can be found, and how access to them can be obtained.

It is hoped that the survey is correct as far as it goes; it is known that it is not complete. New facilities are continually coming to light, but it was thought best to publish an incomplete edition so that some information at least could be disseminated, and it is intended to issue addenda, and possibly a second edition, as further details are accumulated. DWR(D). would be grateful for any corrections, additions, or suggestions for improvement.

We wholeheartedly thank all those individuals, university departments, firms and government departments and establishments who have so freely given us not only all the information we asked for, but their time in exposition.

G.H. HINDS.

SURVEY OF COMPUTING FACILITIES IN THE UNITED KINGDOM

SUMMARY

This report gives a broad review of the different types of computing machines available in the United Kingdom. The computing machines considered are punched card machines, high-speed automatic digital computers, differential analysers, general purpose analogue computers and simulators, network analysers and some special purpose analogue computers. These machines are all considered from the point of view of the work they do rather than the way they are constructed, and some guidance is given on the choice of the machine most suited to a particular problem.

Descriptions of the three main types of computer (punched card machines, high-speed automatic digital computer and differential analyser) are given in Appendix I. Appendix II contains a list of computing facilities in the U.K. together with a list of sources of advice on computational problems.

SURVEY OF COMPUTING FACILITIES IN THE U.K.

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SURVEY OF COMPUTING FACILITIES IN THE U.K.

1. Introduction

Computing machines can be divided roughly into two types:

(a) Digital machines

These operate directly with numbers in their digital form usually by counting discrete objects such as the teeth of a gear wheel or electric pulses. Desk calculators (e.g. the Brunsviga or Friden) are examples of this kind of machine.

(b) Analogue machines

These translate numbers into physical quantities of which the numbers are the measures. Operations are carried out with these quantities and results are obtained in the form of measurements. A slide rule is a very simple example of an analogue machine.

This report deals with the main features of the use of different kinds of computing machines. Brief descriptions of some of these machines are given in Appendix I. Appendix II contains a list of computing facilities in the U.K. and Appendix III describes the organisation of computing within the Ministry of Supply.

It is assumed that the principles and uses of ordinary desk calculating machines are understood and they are therefore not treated in this report. However, Appendix II contains a list of groups using desk calculators together with accounting machines (such as the National) since a much wider range of problems can be solved with this combination of machines.

There are many calculating machines which have been constructed in order to solve one specific problem - e.g. aircraft flutter - and are therefore of very limited application. These are not included in this report.

2. Digital Computers

The ordinary desk calculator will perform the basic operations of addition, subtraction, multiplication and division but numbers must be set and recorded by the operator and these processes account for a large part of the time of calculation, and are liable to introduce errors. Computers with facilities for the storage and recording of data can overcome these disadvantages. Digital machines vary from those that will perform only one operation at a time (e.g. a x b), through those that will perform a series of such operations (e.g. $\sum_{r=1}^{r=n} a_r b_r$), to those that will carry out a complete calculation without intervention by the operator.

3. Punched card equipment

Punched card machines were first developed for census work and are now best known for their application in accounting. In both these applications simple arithmetical operations are carried out on a large volume of numerical data. In recent years these machines have been used for quite complex calculations since these can be split up into sequences of simple operations. Numbers are recorded as holes punched in special cards according to a simple positional code. The cards are then fed into the machine which perform various operations at a fairly high speed on the numbers represented on the cards. These operations include addition, subtraction, multiplication, sorting and comparing. There is a limited amount of storage on counters and the cards themselves are also a very convenient form of storage. Whereas the counters are only a temporary store for numbers during the course of a calculation the cards form a permanent store which can be referred to

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at any future time. One essential feature of these machines is that only a few simple operations can be performed while the cards are passing through a machine. The machines must be set up for any particular sequence of operations by making suitable connections, usually by means of plugboards. Since the plugging of these boards may take a fair length of time, punched card machines are most useful when dealing with large quantities of data.

There are comparatively few organisations using punched card equipment for mathematical work and it is doubtful whether their capabilities have yet been fully explored. It has already been shown that there is a great variety of problems which can be reduced to a form suitable for solution by such machines. These problems include a wide range of statistical calculations, the compilation of mathematical tables, Fourier Analysis and the solution of sets of simultaneous linear equations. The scope could be extended still further in statistical analysis and in the reduction and analysis of trials data.

One great advantage of punched card machines at the moment is that they are standard machines produced for commercial use and are therefore readily available. There are also many problems, particularly those involving a great deal of sorting of data to which they are ideally suited.

New ideas are being incorporated in these machines and several new ones are being developed. These include electronic multipliers and new electro-mechanical multipliers with more storage than former ones which can perform quite long sequences of operations on the numbers on each card. Punched card machines are also being used in conjunction with high-speed automatic computers as a method of feeding in data and receiving information from the computer.

4. High Speed Automatic Digital Computers

This type of computer is a very recent development and the first in this country was completed at Cambridge in 1949. Whereas punched card machines were developed for accounting purposes, the high-speed automatic computers were designed for complex mathematical calculations and it is only quite recently that their application to accounting has been considered. There have been many developments both in the design and use of these computers since 1949 and in England there are now about twelve completed machines and others under construction.

The techniques of electronic engineering have made it possible to build computers that will perform arithmetical operations in times of the order of thousandths of a second instead of seconds as by mechanical means. It is essential with such high calculating speeds that the machine should not be interrupted too frequently by the operator for the insertion of data, scrutiny of intermediate results etc. These machines therefore have a large store which generally holds "instructions" as well as numerical information, so that once these have been fed into the machine it can proceed to do the whole calculation. The instructions are given to the machine in a coded numerical form, stored and then obeyed in sequence. Where the automatic computer differs from other calculating machines is that the sequence in which the instructions are obeyed can be controlled. An automatic computer can obey a certain number of basic instructions which correspond to the keys on a desk machine for adding, multiplying etc. Amongst these instructions are one or more "conditional instructions" which enable the machine to adopt one of several alternative courses according to some specified condition. For instance in an iterative process the machine will perform successive iterations until the difference is less than some specified quantity and will then go on to the next part of the calculation. With other

/calculating

calculating machines the results of each iteration would have to be inspected by the operator who would then make the decision whether or not to proceed to the next stage.

The use of the term "electronic brain" is very misleading in that it gives the impression that these computers have intelligence like a human being. This is not so, and it must be emphasised that a calculating machine is no substitute for the human brain. The "intelligence" of an automatic computer is a combination of the skill of the designer and the ingenuity of the programmer. The machine itself is only capable of obeying instructions and the only decisions it can make are those that result from obeying a series of instructions.

In order to prepare a calculation for an automatic computer the problem must first be translated into the language the machine can assimilate by breaking it up into a series of basic operations such as "multiply x by y", "add a to b" etc. and translating these into a coded form. Instructions must be given to the machine not only for the actual calculation but for many processes which are almost instinctive to operators of desk machines: e.g. counting the number of times a process has been performed and recognizing a change of sign as the signal to go on to the next stage of the calculation. Whereas with ordinary desk calculators the preparation of a problem takes much less time than the calculating time, with high speed automatic computers the preparation, or "programming" is generally the longest part of the work, although the use of standard programmes for routine operation such as deriving square roots, forming sines and cosines etc., can reduce programming time considerably. Now that many problems have been coded it is frequently found that a complete programme can be used again, but if a problem has to be programmed from scratch this will take the greatest part of the time of solution.

These computers reduce the time and cost of many long computations and now make it possible to solve many problems which had previously been considered impossibly lengthy, but they are still not suitable for every type of problem. The feeding in of data is slow in comparison with the calculating time (although new methods of high-speed input and output are being developed) so that at present most statistical problems are more suited to punched card machines. It is also uneconomical to use high-speed automatic computers for small problems unless a ready-made programme exists.

Examples of work that have been done on such computers include the solution of ordinary and partial differential equations, the inversion of matrices, Fourier synthesis and Monte Carlo calculations.

The Ministry of Supply already has one high-speed automatic computer at R.R.E., Malvern. There will also be a Ferranti computer at Fort Halstead similar to the one at Manchester University. The Royal Aircraft Establishment are having an engineered version of the ACE pilot model and also a machine of their own design (RASCAL) which will be a medium-speed computer intended for use on the analysis of experimental results. A good deal of work for the Ministry of Supply has already been done on existing computers. Most computing groups will not undertake programming for problems for other groups so that it has been necessary to train several Ministry of Supply staff to programme one or more of the existing computers. More staff are being trained as the need arises and it is essential that any Establishment which has problems for these computers should have at least one person familiar with programming techniques.

5. Analogue Computers

Analogue computers have two disadvantages in comparison with digital computers. First, they can only deal with particular types of problem. Second, their accuracy is limited by the accuracy of

/their

their physical components, which means that the error is seldom less than 1%. However, in spite of the apparent superiority of digital computers there are many problems far better suited to analogue machines. These include the determination of trends of solutions of problems for ranges of values of input data and the investigation of problems by the experimental method of trial and error. Analogue machines are in fact generally used for problems where a survey of the effect of varying parameters is to be made since this can generally be done very rapidly. The limited accuracy is not usually a disadvantage as in most cases the initial data are no more accurate and only approximate solutions are wanted.

There are vast numbers of analogue machines ranging from very simple devices such as the electrolytic tank to very complex machines such as differential analysers. The majority of analogue machines have been designed for the solution of particular physical problems - e.g. the flight of a guided missile. The only analogue computers which will be considered in this report are those that can be used for generalized mathematical problems - e.g. the solution of simultaneous or differential equations - and thus have uses in many different fields.

6. Differential Analysers

The most important type of analogue computer is the differential analyser. This machine was originally designed to integrate ordinary differential equations, but by skilled operation solutions of a great variety of equations (including algebraic equations and some partial differential equations) can be evaluated. A differential analyser is no substitute for the formal mathematical treatment of differential equations and can only evaluate particular numerical solutions where all the coefficients have numerical values and initial conditions are known.

The basic unit of the differential analyser is some form of mechanism which performs the operation of integration continuously. Whereas the methods of solution of differential equations in digital computers involve replacing the derivatives by finite differences the differential analyser operates directly with these derivatives. A differential analyser therefore consists of a number of integrators, adding mechanisms, etc., which can be connected together in a variety of ways so as to evaluate solutions of different differential equations. These connections between the various units were originally mechanical. Later differential analysers have been built with electrical (servo) connections and the most recent development is the electronic differential analyser.

A differential analyser takes some time to prepare for a particular problem so that if only one solution of an equation, rather than a series of similar ones, is to be evaluated numerical methods may be quicker. Therefore the most suitable problems for a differential analyser are those where a set of solutions is required either for varying initial conditions or for different values of a parameter.

The electronic differential analyser is faster in operation and easier to set up than the mechanical differential analyser. However, it is less accurate and cannot solve such a wide range of equations because integration can only be performed with respect to time.

Differential equations appear frequently in many branches of science so that the differential analyser is a very valuable aid to research. The range of equations that a differential analyser can solve depends primarily on the number of integrators it has. Even a small machine is a very powerful computing aid and can solve a great variety of different equations.

/7.

7. General purpose analogue computers and simulators

The simulator is an analogue machine which is used to set up a direct analogue of a physical system and is generally connected to this system and operates in the same time-scale. It is difficult to give a more precise definition than this since there is great disagreement about what does and does not constitute a simulator. In fact the word "simulator" refers more to the way the machine is used than to the way it is constructed.

The great majority of simulators are used for specific problems - for example simulating the motion of guided weapons or aircraft - and those machines will not be considered in this report.

The general purpose simulator consists of a number of units which can be connected together in a variety of ways. These units may be for performing basic mathematical operations such as addition, integration etc. or they may be direct analogues of components in a physical system such as phase advance, time delay etc.

The term simulator therefore covers a great variety of analogue machines ranging from electronic differential analysers to machines of very restricted use which simulate one particular system. The use of the general purpose simulator is very similar to that of the differential analyser and a correspondingly wide range of problems can be solved.

8. Network Analysers

Electrical network analysers were originally built for studying network problems in connection with the transmission of electrical power and voltage-current characteristics in systems where power loads and power sources may vary rapidly with time. However, in recent years more general use has been found for these machines.

There are two main types of network analyser:

(a) The D.C. or resistance analyser

This is a system of coupled resistance circuits which can be flexibly arranged to simulate the steady-state conditions existing in an electrical or mechanical problem. In addition to many applications such as distribution problems (which are mainly concerned with the voltage regulation and position of minimum voltage) and the study of symmetrical and assymmetrical networks, there are many other uses for D.C. analysers. Examples are steady-state solutions for compressible fluid flow and heat flow, the solution of Laplace's equation and mechanical engineering problems such as those met with in beam theory.

(b) The A.C. Analyser

There are two types of A.C. analyser:

(i) The conventional impedance analyser

This provides a true miniature representation of the actual network using variable resistances, inductances, capacitances, and phase-shifting transformers with an inter-connecting jumper system.

(ii) The unconventional A.C. analyser

This does not use physical circuit parameters as such, but rather solves the mathematical problem created by the original network. The Blackburn analyser is an example of this type of machine. This uses multi-winding transformers for the circuit units.

The A.C. analyser is more flexible than the D.C. analyser since it can represent phase relationships between currents and voltages in various parts of the network and is therefore capable of handling complex quantities directly.

A wide range of problems can be solved with these machines. Examples are, solutions of the Schrödinger equation for a simple harmonic oscillator and for the rigid rotator in one dimension and studies of the propagation of electro-magnetic waves.

Some special networks have also been constructed for the solution of sets of simultaneous linear algebraic equations and for the solution of Laplace's and Poisson's equation. These will be described in section 9.

9. Other analogue computers

(a) The Isograph

This is an instrument for solving polynomial equations up to a certain degree (the machine at R.A.E. will deal with those up to the 6th degree). Its operation is based on drawing the Argand diagram of the polynomial corresponding to a fixed value of the modulus of the independent variable for all values of the argument. If the modulus is chosen equal to one of the roots of the equation the Argand diagram will pass through the origin. Otherwise it will encircle the origin a number of times equal to the number of roots less than the chosen value. By varying the modulus it is thus possible to locate all the roots.

(b) The Electrolytic Tank

This is an extremely simple type of analogue computer. It consists of a shallow tank of electrolyte together with electrodes and exploring probes. The electric potential within the tank obeys Laplace's equation. Since the real and imaginary parts of all analytic functions of a complex variable also satisfy Laplace's equation it follows that such functions can be represented by the potential within the tank. There are therefore many uses for this device.

(c) Simultaneous Equation Solvers

Several machines have been designed to solve sets of simultaneous linear equations and these have already been mentioned briefly under network analysers. The machine designed by Mallock at Cambridge is an a.c. network using multi-winding transformers, the one at R.A.E. is a d.c. resistance network.

(d) Machines for the solution of Laplace's and Poisson's Equations

Another special form of network analyser is a resistance network for obtaining solutions of these equations. A network for the solution of the three dimensional, form of Laplace's equation has been constructed, and others have been made for the two dimensional form. These machines in effect solve the finite difference forms of the equations by relaxation techniques.

10. Planning a computation

(a) It is not always easy to decide what method of computation should be used for any particular problem. Some problems can only be solved in one way whereas with others several alternative methods may be possible. The final decision will involve considerations of cost, accuracy, speed, availability of machines and so on as well as the mathematics of the problem. There are several centres where advice on computing can be obtained and these are listed in Appendix II.

../(b)

(b) It is important to understand the way different types of computing machines work before planning computations in detail. The essence of mechanized computing is repetition, so that an instruction can be given once and obeyed a large number of times. It is nearly always easier when using computing machines to repeat a sequence of operations many times rather than to change the sequence and this means that many of the short-cuts taken in hand computing are not suited to machines. High-speed automatic computing has already shown that many computing processes previously thought to be of no practical value can in fact be extremely useful. The problem must therefore be considered as a whole and the computation planned with the machine in mind so that the best way for that machine can be found.

(c) It must be remembered that it is not only the actual calculating time that must be considered when comparing times of solution by different machines. There is the preparation of data (i.e. punching cards or tape, drawing graphs etc.), the preparation of the machine (programming, preparing plugboards, setting up a differential analyser etc.) and lastly obtaining the results (printing from punched cards, taking readings from counters, measuring voltages etc.) and the time for these processes must be added to the actual calculating time.

(d) The decision as to whether to use analogue or digital machines for a particular problem depends not only on the type of problem but the number of solutions required. Analogue machines are in general most suited to problems requiring a large number of solutions corresponding to variations in parameters. However, the accuracy of analogue machines is not very great so that if accurate solutions are required a digital computer would be necessary. Sometimes a range of solutions is investigated on an analogue machine and a digital computer is then used to obtain accurate solutions at a few points.

Punched card machines and high-speed automatic computers are in general suited to different kinds of problems. Roughly speaking, punched card methods are best for problems involving simple operations on a large quantity of data and high-speed computers are most suited to those involving more complex operations on a small amount of data.

(e) Experimental work frequently provides a great bulk of data which presents many problems - from the method of recording the data to the last stages of calculation and presentation of results. Ideally the problem should be considered as a whole, but in fact it is often considered in separate steps and little thought is given in the early stages to the methods that will or might be used when analysing the data. Efforts are being made to co-ordinate and mechanise the recording and analysis of all sorts of experimental work, such as results of firing trials, aircraft flight trials and wind tunnel experiments. The process of converting results in the form of measurements into a digital form at present consumes a great deal of time and there is a need for devices that will do this automatically, leaving the data in a form suitable for direct input to an automatic digital computer.

(f) There are still many scientists and engineers who know very little of the potential uses of large scale computing machines. Desk calculators are still being used for problems which could be solved more efficiently on larger machines. Although high-speed computing machines are very expensive their cost is outweighed by the increase in the amount of work they can do. Often a problem is not tackled in the best way and many simplifications have to be made to enable a solution to be obtained by conventional computing techniques. The advent of high-speed computing machines, by making it possible to solve problems which would otherwise be impossible, should turn research into new channels. Once the scientist knows that these machines exist and can be of great assistance to him, he will cease to be confined within the limits imposed by the speed and cost of hand computing.

/Acknowledgements

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It is desired to thank all the establishments and firms who have given the data in Appendix II and without whose help this report could never have been written. In particular the staff of the Maths. Services Department at R.A.E., the Mathematics Division at N.P.L. and the Maths. Laboratory at Cambridge have been esepcially helpful and patient on the many occasions when their advice has been sought.

APPENDIX I

DESCRIPTIONS OF MAIN TYPES OF MACHINES

A. Punched Card Equipment

There are three types of punched card machines in the UK:- Powers Samas, Hollerith and I.B.M. Powers Samas machines are more suited to large-scale routine calculations, such as census work and accounting, and are seldom used for mathematical calculations. Hollerith and I.B.M. machines are more flexible and are very similar. Brief descriptions of the various Hollerith machines will be given.

Sorter can be set to sort on any column of the cards and will separate the cards into twelve pockets according to the numbers 0-9, x and y punched in that column. There is also a reject pocket for cards with no hole in that column.

Collator. Compares readings from one card with those on another. It has a variety of uses such as: checking that a pack of cards is in correct ascending or descending sequence, merging one pack with another and selecting cards from a large pack which will match against those of a smaller one.

Tabulator. Usually has six 11-wheel counters together with selectors, control mechanisms and facilities for transferring numbers from one counter to another. It is essentially an adding and printing machine. The control and selector features make it possible to form sub-totals at suitable times, add only the numbers from the cards with particular codings, separate positive and negative numbers, etc. Methods of progressive addition provide a rapid means of forming sums of products and squares. Results can be printed, or punched on cards by means of a summary punch.

Reproducing Summary Punch. Information can be copied from one card to another in a number of ways, and the machine itself can check that the numbers have been punched correctly. It is possible to copy information from a "master card" on to all the succeeding cards until another master card is reached. This machine can be used in conjunction with the tabulator to obtain results on cards.

Multiplier. The standard machine can multiply two 8-figure numbers and punch the result on the same card. It also has facilities for adding or subtracting two numbers on the same card. Extra relays can be fitted so that signed multiplications can be done.

The Hollerith 506 and I.B.M. 602A multipliers are far more flexible and are more like small automatic computers. They have counters, selectors and control features which enable them to combine the functions of the tabulator and multiplier.

Normal Operating Speeds of Hollerith Machines

Sorter:	400 cards per minute.
Collator:	240 cards per minute for each feed.
Tabulator:	Addition. 150 cards per minute.
Reproducer:	100 cards per minute.
Multiplier:	(a) Multiplying 2 8-digit numbers and punching 16 digit products, 11 cards per minute.
	(b) Multiplying 2 8-digit numbers and accumulating the products, 15 cards per minute.

/506 Multiplier:

506 Multiplier: (a) Multiplying 8 digit numbers by 12 digit numbers and punching result, 15 cards per minute.

(b) Accumulating products 20 cards per minute.

B. High-speed Automatic Digital Computers

There are several different types of machine and the details of construction vary considerably from one machine to another. However, the basic principles are common to all machines.

Input. There must be some means of getting information into the computer. This information is generally on Hollerith punched cards or teleprinter tape.

Output. Information is usually received from the machine in the same form as it was given. It is sometimes printed by means of a teleprinter or electric typewriter.

Storage. Instructions and data are stored inside the machine. The amount of information that can be stored varies with the size of the machine and the type of storage. There are three main types of storage at present in use.

(1) Mercury delay line. Numbers are represented as strings of pulses which are circulated through the delay-line.

(2) Cathode Ray Tube. Numbers are stored as charge patterns on the screen of a cathode ray tube and are read by a beam of electrons.

(3) Magnetic Drum. Numbers are stored as small areas of magnetisation on the surface of a rotating drum. This is a means of storing a very large amount of information and has the advantage that this information is not lost when power is switched off. The disadvantage is that the time taken to read off a number is slow in comparison with other forms of storage.

Magnetic drum storage is generally used in conjunction with another and faster form of storage, such as (1) and (2) above.

Arithmetical Unit. This is the part of the computer that carries out the arithmetical operations called for by the instructions. Its properties vary, but will certainly include addition, subtraction and sign sensing.

Control Unit. This part of the computer can be compared with the operator of a desk calculator. It sees that the instructions are obeyed in the right order and makes any necessary discriminations.

In nearly all automatic computers numbers are represented inside the machine in binary form - that is by a combination of 0's and 1's. Thus 10011 represents $1 + 1 \times 2 + 1 \times 2^4 = 19$ in the decimal system. The binary system is very easily translated into electrical pulses, or

/whatever

whatever the method of storage requires. A one is represented by a pulse and a nought by no pulse, and similarly for other so-called "on-off" elements. In most cases the programmer need hardly be aware of the fact that numbers are in binary form inside the machine since the machine itself will convert numbers from decimal to binary on receiving them and vice versa on output.

Each computer is capable of obeying a certain number of basic instructions. An example will be given of some of the instructions for the "EDSAC" at Cambridge in their coded form. The results of most operations appear in a special register called the accumulator.

A n   Add the number in storage location n into the accumulator.

S n   Subtract the number in storage location n from the accumulator.

H n   Copy the number in storage location n into the multiplier register.

V n   Multiply the number in storage location n by the number in the multiplier register and add the product into the accumulator.

T n   Transfer the contents of the accumulator to storage location n and clear the accumulator.

U n   Transfer the contents of the accumulator to storage location n and do not clear the accumulator.

E n   If the number in the accumulator is greater than or equal to zero the next instruction to be obeyed is in storage location n. Otherwire proceed serially.

etc.

The last instruction is an example of a "conditional instruction".

There are many different types of code in use. All codes must specify one or more addresses (i.e. locations in the store of operands, destinations of results, etc.). The EDSAC code is an example of a One-address code. There are also two, three and four address codes, which specify some combination of the following addresses:- operator, operand, destination of result and source of next instruction.

Many types of storage have the disadvantage that there must be a delay while waiting for information to become available. Optimum coding is designed to take this into account by arranging the information so that it is available at the time that it is required. The simplest form of optimum coding is by means of a two address code. specifying the operator and the next instruction. This enables instructions to be so placed in the store that each one is available immediately after the previous instruction has been obeyed.

C. The Differential Analyser

(i) Mechanical and electro-mechanical

A differential analyser consists of a number of units each of which carries out an operation which can be regarded as a translation into mechanical terms of a process (integration, addition etc.) which may be required in the solution of a differential equation together with some means of inter-connecting these units. Mechanical and electro-mechanical differential analysers differ in the type of connection employed but are otherwise similar. In the former case these

/connections

connections are made by means of shafts and gears and in the latter by electrical transmitters. Each unit of the machine is driven by the rotation of one or more shafts and the result of its operation is the rotation of another shaft. Each shaft represents one of the quantities in the equation to be solved and these shafts are connected together in such a way that the relations between their rotations form a translation into mechanical terms of the equation to be solved.

Any continuously variable gear can be used as an integrating mechanism. Suppose there is a mechanism giving a continuously variable gear ratio 1 : n between the rotations of driving and driven shafts. Then for a rotation dx turns of the driving shaft the rotation of the driven shaft is ndx turns. If the gear ratio n is changing as the driving shaft is rotating, the total rotation of the driven shaft is the sum of the elements of rotation ndx - i.e. $\int$ ndx. To be suitable for a differential analyser such a mechanism should be able to be set accurately to any gear ratio n in its range and should include both positive and negative values of n including n = o in this range.

Input to the machine is by means of input tables whereby a graph is followed and the information translated into the rotation of a shaft which can then be fed to other parts of the machine. Output is by means of similar function tables when a graphical solution is required or by counters for tabulated solutions. Many differential analysers also have a double input-output table which has a variety of uses. By means of this table an index can be made to follow in the course of a solution a curve drawn earlier in the course of the same solution. It may also be used for multiplication and division.

The time of solution of a problem depends on the nature and range of the solution required, and may be anything from a few minutes to an hour or more. This time refers only to the actual running time of the machine and not to the planning, setting up etc. which might take only a few hours or several days.

(ii) Electronic Differential Analysers

The basis for all electrical analogue computers is the mathematical relation between currents and voltages in electric circuits. Electronic differential analysers consist of various units corresponding to the units of mechanical analysers for integration, summation etc. Integration can be performed by using resistance-capacity circuits in conjunction with electronic amplifiers, addition and subtraction by the use of two identical triodes in parallel in a resistance-coupled amplifier and so on.

The Philbrick electronic differential analyser at R.A.E. consists of a number of units such as integrators, adders, multipliers which can be arranged as required and connected together by plugs. It is extremely easy to use and rapid in operation. Results appear as traces on a cathode ray tube and although the solution is almost instantaneous it is repetitive so that a continuous display can be seen. More units can be added to the computer although as this is an American machine these units are not easily obtainable.

APPENDIX II

A. ADVICE ON COMPUTING

National Physical Laboratory, Teddington, Middlesex.	
Scientific Computing Service Ltd., 23 Bedford Square, London, W.C.1.	
British Tabulating Machine Co. Ltd., 17 Park Lane, London, W.1.	Punched Card Work.
Dept. of Applied Mathematics, The University, Liverpool, 3.	Hand Computing.

B. DESK CALCULATORS AND NATIONAL OR SUNDSTRAND ACCOUNTING MACHINES

National Physical Laboratory, Teddington, Middlesex.	30 hand, 12 electric, 3 adding, listing, 1 National class 3000, 1 National class 31.
Scientific Computing Service Ltd., 23 Bedford Square, London, W.C.1.	18 hand, 4 electric, 1 National class 3000 (Access to Hollerith and electronic computers.)
Dept. of Applied Mathematics, The University, Liverpool, 3.	23 hand, 1 electric, 1 Victor adding, 1 National class 3000.
H.M. Nautical Almanac Office, Herstmonceux Castle, Nr. Hailsham, Sussex.	11 hand, 4 electric, 2 Nationals.
Maths Services Division, R.A.E., Farnborough.	15 hand, 16 electric, 1 National.
Admiralty Research Laboratory, Teddington, Middlesex.	1 Sundstrand, 9 hand, 3 electric.
Ordnance Board, Charles House, Kensington High Street, London, W.14.	3 National class 31, 1 National class 3000. 18 electric, 10 hand.
SSAM, A.R.E. Fort Halstead, Sevenoaks, Kent.	6 hand (including one twin Brunsvija) 15 electric, 5 Nationals.

C. PUNCHED CARD MACHINES

Location	Machines	Type of Work	Notes
National Physical Laboratory, Teddington, Middlesex.	Large installation of all types of Hollerith Machines. Also I.B.M. 602A.	General. Also research into methods.	Computing service provided.
Royal Aircraft Establishment, Farnborough, Hants.	Hollerith. tabulator, sorter, collator, reproducing summary, punch, multiplier.	General.	
British Tabulating Machine Co.Ltd., 17 Park Lane, London, W.1.	Hollerith tabulator, sorter, collator, reproducing summary, punch, 506 multiplier.	General.	Computing service provided.
Building Operations Research Unit, Block 5, Montagu Mansions, Crawford Street, London, W.1.	Hollerith tabulator, sorter, collator, reproducing summary punch, multiplier.	Mathematical statistics.	
Nautical Almanac Office, Herstmonceux Castle, Nr. Hailsham, Sussex.	Hollerith tabulator, sorter, collator, reproducing summary punch. IBM 602A multiplier.	Mainly compilation of tables.	
De Havilland Propellers Ltd., Manor Road, Hatfield, Herts.	IBM 602A, sorter and reproducer.	Mainly vibration problems.	
University Mathematical Laboratory, Free School Lane, Cambridge.	Hollerith tabulator, sorter, reproducer.	Mainly crystallographical.	

D. HIGH-SPEED AUTOMATIC DIGITAL COMPUTERS

NAME:	EDSAC. (Electronic delay storage automatic calculator).	LEO (Lyons Electronic Office)
LOCATION:	University Mathematical Laboratory, Free School Lane, Camb.	J. Lyons & Co. Ltd., Cadby Hall, London, W.14.
HEAD OF GROUP:	Dr. M.V. Wilkes	Mr. T.R. Thompson
WHEN READY:	1949	1951
SIZE:	15 racks of $2\frac{1}{2}$' x 7' x 9"	20 racks of 3' x 7' x 9" about 5,000 valves.
SPEED (1) ADD. (INCL. ACCESS ETC.)	1.4 milliseconds average	1.4 milliseconds average
(2) MULTIPLY (..)	5.2 milliseconds average	5.2 milliseconds average
(3) ACCESS TO STORE	248-904 microseconds	248-904 microseconds
SCALE:	Binary	Binary
POINT	Fixed (after 1st digit)	Fixed
DIGITS/WORD	17 or 35	17 or 35
AUTOMATIC ARITHMETICAL OPERATIONS	+, −, x	+, −, x
CODE (1) NO.OF ADDRESSES	1	1
(2) DIGITS/ INSTRUCTION	17	17
INPUT (1) MEDIUM	Teleprinter tape.	Teleprinter tape) Normal
(2) SPEED	36 characters/second	28 characters/sec. average) Normal. Also high-speed.
OUTPUT (1) MEDIUM	Teleprinter tape	Teleprinter) Normal
(2) SPEED	16 characters/second	7 characters/sec.) Normal. Also high-speed.
STORAGE (1) TYPE	Mercury delay-line Magnetic tape	Mercury delay line
(2) CAPACITY	960 short words delay line. Unlimited tape storage.	2048 17 digit words
OPERATION	Serial	Serial
NOTES	(1) A new computer is being designed. (2) A large library of sub-routines has been built up.	(1) This is an engineered version of the EDSAC. with a few minor differences. (2) High-speed input and output is comparable with working speed. (3) Computing service provided.

NAME:	ACE Pilot Model. (Automatic Computing Engine)	(Manchester Mark II Computer (Ferranti Mark I.
LOCATION:	National Physical Laboratory, Teddington, Middlesex.	The University, Manchester, 13.
HEAD OF GROUP:	Dr. E.T. Goodwin	Professor F.C. Williams
WHEN READY:	1951	1951
SIZE:	45 racks each 30" x 7½" x 2" 1,000 valves.	6 racks (each occupying approx. 5½' x 3' floor space)
SPEED: (1) ADD (INCL. ACESS ETC.)	64 microseconds minimum.	1.2 milliseconds
(2) MULTIPLY (..)	2 milliseconds.	2.16 milliseconds
(3) ACCESS TO STORE	64-1000 microseconds	10 microseconds
SCALE:	Binary	Binary
POINT:	Fixed	Fixed
DIGITS/WORD	32	20 or 40
AUTOMATIC ARITHMETICAL OPERATIONS	+, -, x	+, -, x
CODE (1) NO.OF ADDRESSES	3	1
(2) DIGITS/ INSTRUCTION	32	20
INPUT (1) MEDIUM	Hollerith cards	Teleprinter tape
(2) SPEED	1280 digits/second	Max. 200 characters/second
OUTPUT (1) MEDIUM	Hollerith cards	Teleprinter tape and/or electromatic typewriter.
(2) SPEED	640 digits/second	15 characters/second tape 6½ characters/second print.
STORAGE (1) TYPE	Mercury delay lines	Cathode ray tube and magnetic drum.
(2) CAPACITY	360 words	Cathode ray tube 512 20 digit words. Magnetic drum. Max.16,384 "
OPERATION	Serial	Serial
NOTES	(1) Optimum coding. (2) Magnetic drum storage will be added. (3) Several engineered versions of this machine are to be made. They will be known as "DEUCE"	(1) Ferranti are making several similar computers (e.g. See AMOS). (2) The University is working on the design of a new computer which will be a parallel machine with cathode-ray tube store.

NAME:	MOSAIC Ministry of Supply Automatic Integrator and Calculator.	T.R.E. Parallel Digital Computer.
LOCATION:	Radar Research Establishment, Leigh Sinton Road, Malvern, Worcs.	Radar Research Establishment, Great Malvern, Worcs.
HEAD OF GROUP:	Mr. P.H. Blundell	Dr. A.M. Uttley
WHEN READY:	1953	1953
SIZE:	11 8' double sided racks. About 6,000 valves	10 $8\frac{1}{2}$' P.O. racks 1,950 valves.
SPEED (1) ADD (INCL. ACCESS ETC.)	.14 milliseconds minimum	40 microseconds.
(2) MULTIPLY (..)	5.88 milliseconds minimum	10 milliseconds (programmed).
(3) ACCESS TO STORE	1.12 milliseconds maximum	5 microseconds (high speed store).
SCALE:	Binary	Binary
POINT:	Fixed	Fixed, after 1st binary digit
DIGITS/WORD	40	24
AUTOMATIC ARITHMETICAL OPERATIONS	+, −, x	+, −.
CODE (1) NO.OF ADDRESSES	4	1
(2) DIGITS/ INSTRUCTION	40	14
INPUT (1) MEDIUM	(1) Normal-Hollerith cards. Special purpose 30 hole monotype tape.	Punched tape.
(2) SPEED	(2) Hollerith. 1600 digits/second max. Tape. 4-5 rows/sec.	17 characters/second.
OUTPUT (1) MEDIUM	Hollerith cards and electromatic typewriter.	Punched tape or print.
(2) SPEED	800 digits/sec.Hollerith. 10 characters/sec. typewriter.	10 characters/sec. punch. 7 characters/sec. print.
STORAGE (1) TYPE	Mercury delay-lines	Cathode ray tube and magnetic drum.
(2) CAPACITY	1036 40 digit words 1 80 digit words	512 words cathode ray tube. 2048 or 65536 words magnetic drum.
OPERATION:	Serial	Parallel
NOTES:	(1) Optimum coding (2) This machine is intended for use mainly on trials analysis.	(1) Active states for "0" and "1". (2) Built for development of computers and associated circuitry. Will also be used by TRE. Maths Division.

NAME:	AMOS. (Automatic Computer Ministry of Supply).
LOCATION:	ARE., Fort Halstead, Sevenoaks, Kent.
HEAD OF GROUP:	Dr. J.W. Maccoll
WHEN READY:	End of 1953
SIZE:	6 racks (each occupying approx. $5\frac{1}{2}'$ x 3' floor space.
SPEED (1) ADD (INCL. ACCESS ETC.)	1.2 milliseconds
(2) MULTIPLY (..)	2.16 milliseconds
(3) ACCESS TO STORE	10 microseconds
SCALE:	Binary
POINT:	Fixed
DIGITS/WORD	20 or 40
AUTOMATIC ARITHMETICAL OPERATIONS	+, -, x
CODE (1) NO.OF ADDRESSES	1
(2) DIGITS/ INSTRUCTION	20
INPUT (1) MEDIUM	Teleprinter tape
(2) SPEED	Max. 200 characters/second
OUTPUT (1) MEDIUM	Teleprinter tape and print
(2) SPEED	15 characters/second tape. High-speed print 160 characters/second.
STORAGE (1) TYPE	Cathode-ray tube and magnetic drum
(2) CAPACITY	Cathode-ray tube 512 20 digit words Magnetic drum Max 16,384 "
OPERATION	Serial
NOTES:	(1) This computer was made by Ferranti and is almost identical with the one at Manchester University.

NAME:	ICCE. (Imperial College Computing Engine)
LOCATION:	Imperial College of Science and Technology, South Kensington, London, S.W.7.
HEAD OF GROUP:	Dr. K.D. Tocher
WHEN READY:	1952
SIZE:	
SPEED (1) ADD (INCL. ACCESS ETC.)	Average 50 milliseconds
(2) MULTIPLY (..)	Approx. 2/5 second
(3) ACCESS TO STORE	Minimum 10 ms.
SCALE:	Binary
POINT:	Fixed
DIGITS/WORD	19 and sign. Short number unit 5 and sign.
AUTOMATIC ARITHMETICAL OPERATIONS	+, −, x, ÷
CODE (1) NO.OF ADDRESSES	Variable
(2) DIGITS/ INSTRUCTIONS	Variable
INPUT (1) MEDIUM	Hollerith cards
(2) SPEED	50-60 words/minute
OUTPUT (1) MEDIUM	Printing by Hollerith tabulator
(2) SPEED	
STORAGE (1) TYPE	Relays and punched tape
(2) CAPACITY	
OPERATION	Parallel
NOTES	1) This is a relay computer.

NAME:	-	RASCAL R.A.E. Sequence Controlled Calculator Mark II.
LOCATION:	Atomic Energy Research Establishment, Harwell, Didcot, Berks.	Royal Aircraft Establishment, Farnborough, Hants.
HEAD OF GROUP:	Dr. J. Howlett	Dr. S.H. Hollingdale
WHEN READY:	1952	Prototype in 1954
SIZE:	4 7' racks 1 6' racks	Portable. Probably in 4 "suitcases".
SPEED (1) ADD (INCL. ACCESS ETC.)	2.2 seconds) This includes reading instruction from tape.	(1) 10 milliseconds.
(2) MULTIPLY (..)	5-15 seconds)	(2) 20 milliseconds.
(3) ACCESS TO STORE	-	(3) To 1,100 locations nil. To remainder about 30 milliseconds.
SCALE:	Decimal	Decimal
POINT:	Fixed after 1st digit	Floating $\pm$ p x 10^j where $0 \leq p < 1$ and $-19 \leq j \leq +29$.
DIGITS/WORDS	5 or 8	11
AUTOMATIC ARITHMETICAL OPERATIONS	+, -, x, ÷	+, -, x.
CODE (1) NO.OF ADDRESSES	2	2
(2) DIGITS/ INSTRUCTION	5	11
INPUT (1) MEDIUM	Paper tape (8 readers)	Punched film or Hollerith cards.
(2) SPEED	About 1 second per instruction	500 characters/sec. film. 250 characters/sec. cards.
OUTPUT (1) MEDIUM	Teleprinter or punched tape.	Typewriter, punched tape and Hollerith cards.
(2) SPEED	Select tabulation and print 8 digits in 11 secs.	Maximum 36 characters/sec.
STORAGE (1) TYPE	Dekatron tubes	Magnetic drum
(2) CAPACITY	40 words (can be extended to 90)	10,000 words
OPERATION:	Parallel	Parallel
NOTES:	(1) This is a slow computer and the speed is about equivalent to desk calculators. (2) The machine can run continuously and unattended for several days. (3) This computer is not entirely electronic and includes many relays. (4) A new computer is being designed.	(1) This will be a low cost, medium speed portable machine intended mainly for use on the reduction of experimental data. (2) Further similar machines will probably be made.

NAME:	NICHOLAS	401 Mark I.
LOCATION:	Elliott Bros. Ltd., Research Laboratories, Borehamwood, Herts.	University Mathematical Laboratory, Cambridge.
HEAD OF GROUP:	Mr. N.D. Hill	Mr. W.S. Elliott
SIZE:	6 7 ft. racks.	12'6" x 21" x 7'9" (6 cabinets)
SPEED (1) ADD (INCL. ACCESS ETC.)	Average 6 millisecs.	204 microsecs. minimum.
(2) MULTIPLY (..)	8.16 millisecs. + access	3 millisecs. + access
(3) ACCESS TO STORE	Maximum 12 millisecs.	Maximum 13.3 millisecs.
SCALE:	Binary	Binary
POINT:	Fixed (after first binary digit)	Fixed (after first binary digit)
DIGITS/WORD	32	32
AUTOMATIC ARITHMETICAL OPERATIONS.	+, -, multiplication of two positive numbers.	+, -, x
CODE (1) NO.OF ADDRESSES	1	2
(2) DIGITS/ INSTRUCTION	16	32
INPUT (1) MEDIUM	Teleprinter tape	Teleprinter tape
(2) SPEED	5-10 characters/sec.	5-10 characters/sec.
OUTPUT (1) MEDIUM	Teleprinter	Olivetti typewriter
(2) SPEED	5-6 characters/sec.	Approx. 10 characters/sec.
STORAGE (1) TYPE	Nickel delay line	Magnetic disc
(2) CAPACITY	1024 words	1024 words
OPERATION	Serial	Serial
NOTES:	(1) This is a laboratory model for use on general problems by Elliott Bros. Theory Group. (2) Computing service provided.	(1) Optimum coding. (2) This computer is fully engineered using packaged units. (3) This computer is owned by NRDC. and will probably be moved to their premises at 1 Tilney St. fairly soon. (4) Elliott's propose making further similar machines for sale.

NAME:	APE(R)C. All purpose electronic (Rayon) Computer.	-
LOCATION:	British Rayon Research, Manchester.	British Tabulating Machine Co. Ltd., 17 Park Lane, London, W.1.
HEAD OF GROUP:		Mr. R.L. Michaelson
WHEN READY:	1952	1953
SIZE:	6' x 4' x 6" (2 P.O. racks) 425 valves	2 P.O. racks
SPEED (1) ADD (INCL ACCESS ETC.)	5 millisecs. minimum	5 millisecs. minimum
(2) MULTIPLY (..)	20-600 millisecs.	20-600 millisecs.
(3) ACCESS TO STORE	Maximum 20 millisecs.	Maximum 20 millisecs.
SCALE:	Binary	Binary
POINT:	Fixed, after 1st binary digit	Fixed, after 1st binary digit
DIGITS/WORD	32	32
AUTOMATIC ARITHMETICAL OPERATIONS	+, -, x.	+, -, x.
CODE (1) NO. OF ADDRESSES	2	2
(2) DIGITS/ INSTRUCTION	32	32
INPUT (1) MEDIUM	Teleprinter keyboard	Hollerith cards
(2) SPEED	Maximum 7 decimal digits/sec.	32 binary digits/sec.
OUTPUT (1) MEDIUM	Teleprinter	Print: Hollerith tabulator
(2) SPEED	7 decimal digits/sec.	8 decimal digits in $\frac{3}{4}$ sec.
STORAGE (1) TYPE	Magnetic drum	Magnetic drum
(2) CAPACITY	512 words	256 words
OPERATION	Serial	Serial
NOTES:	(1) This machine was designed and built by Dr. A.D. Booth, Birkbeck College, London. (2) He is now working on a similar machine called APE(x)C which will be rather faster than APE(R)C.	(1) This is a commercial version of the APE(R)C and is an experimental model. (2) Similar computers are being built for sale at approximately £14,000.

E. DIFFERENTIAL ANALYSERS

Location	No. of integrators	Type	Input and Output tables	Notes
National Physical Laboratory, Teddington, Middlesex.	8	Mechanical	5 single 1 double	
N.P.L. Teddington, Middlesex.	20	Electro-mechanical	6 single 4 double	
R.A.E., Farnborough, Hants.	6	Electro-mechanical	4 single	This machine will be removed from RAE. when their electronic digital computer (DEUCE) is installed.
R.A.E., Farnborough, Hants.	6	Electronic	-	Results are shown as traces on a cathode ray tube. This machine is constructed in units and connections are made by plugs. More units can be added so that the machine is not restricted to 6 integrators. There are also units for adding, multiplying, function generating, etc.
Royal Military College of Science, Shrivenham, Wilts.	8	Mechanical	5 single 1 double	The R.M.C.S. has also a small 4 integrator meccano differential analyser. This is very simple to use and ideal for small problems.
Courtaulds Research Laboratories, Lower Cookham Road, Maidenhead, Berks.	8	Mechanical	5 single 1 double	
Building Research Station, Garston, Watford, Herts.	10	Mechanical	2 single 2 double	Under construction.
I.C.I. Ltd., Butterwick Research Laboratories, The Frythe, Welwyn, Herts.	6	Mechanical		
Elliott Brothers, Research Laboratories, Borehamwood, Herts.	6	Electro-mechanical	3 input 1 rotary input 1 double	
R.R.E., Great Malvern, Worcs.	4	Electro-mechanical	1 output 1 input or output	

E. DIFFERENTIAL ANALYSERS (Continued)

Location	No. of integrators	Type	Input and Output tables	Notes
Dept. of Physics, King's College, Strand, London, W.C.1.	4	Electronic		Both these machines were designed primarily for research into computing techniques. The 6-integrator differential analyser (which can be readily adapted for more integrators) has a multi-dimensional display enabling up to 1024 different trial solutions to be displayed.
Dept. of Physics, King's College, Strand, London, W.C.1.	6	Electronic		

F. GENERAL PURPOSE ANALOGUE COMPUTERS AND SIMULATORS

Location	Description
Guided Weapons Department, R.A.E., Farnborough, Hants.	Electronic general purpose simulator (Gepus). Includes 16 integrators, 15 summing amplifiers, 12 curve followers of function generators, 15 multipliers and 30 "combined units". All input and output connections are taken to a plug-and-jackboard on a central control desk which also has recorders, C.R. oscilloscope etc.
Short Bros. & Harland Ltd., Castlereagh, Belfast.	A general purpose analogue computer which can be used as a simulator. Suitable for use by operators with no specialised electronic knowledge. Includes 12 amplifiers (for integration and summation), 12 function units (for differentiation, phase shifting etc.) and 24 scaling units. More units - e.g. multipliers - will be developed later. This computer is a prototype. Later models will be made for sale.
Vickers Armstrongs Ltd., Weybridge, Surrey.	(1) A general purpose analogue computer which can be used as a simulator. It is suitable for use only by technicians since interconnections are made by soldering in resistances and condensers. This machine has 20 amplifiers which can be used to add or integrate. (2) A computer, comprising 24 amplifiers wired to solve 6 simultaneous 2nd order equations. All coefficients are set on dials.
National Physical Laboratory, Teddington, Middlesex.	Servo-simulator, designed to simulate any closed-loop control system including both linear and non-linear elements. Direct analogue units used such as exponential time delay, pure time delay, square wave and pulse generator, phase advances etc.
Sperry Gyroscope Co. Ltd., Great West Road, Brentford, Middlesex.	General purpose analogue computer. 10 DC amplifiers associated with R-C units which may be switched to give 12 different forms of transfer function. There are two similar machines which can be coupled together for complicated problems which are beyond the capacity of one.

G. NETWORK ANALYSERS

Merz & McLellan, Carliol House, Newcastle-on-Tyne 1.	One d.c. resistance analyser and one a.c. analyser of the transformer analogue type. This latter was the first of its kind to be constructed and is at present in course of modernisation.
A. Reyrolle & Co., Hebburn-on-Tyne.	One d.c. analyser and one conventional a.c. analyser.
Imperial College, London, S.W.7.	Transformer analogue type a.c. network analyser.
Northampton Polytechnic, St. John Street, London, E.C.1.	One d.c. analyser. Transformer analogue type a.c. analyser under construction.
Associated Electrical Industries, Neasden Lane, Willesden, London, N.W.10.	Conventional a.c. analyser.
English Electric Co., Nelson Laboratories, Stafford.	One resistance analyser and one conventional a.c. analyser.
Electrical Research Association, Perivale, Middlesex.	One resistance analyser. A conventional a.c. analyser is under construction.

H. OTHER ANALOGUE COMPUTERS

Location	Type of Machine
Maths. Services Division, RAE. Farnborough, Hants.	1) Isograph. For calculating roots of polynomial equations up to the 6th degree. 2) Simultaneous Equation solver. Will solve sets of up to 12 simultaneous linear equations.
Imperial College of Science and Technology, South Kensington, London, S.W.7.	Electrolytic tank.
Boulton Paul Aircraft Ltd., Wolverhampton.	1) Two Dimensional Potential Analyser. Resistance network for solving the Laplace and Poisson equations in two dimensions. 2) Three Dimensional Potential Analyser. A resistance network for solving Laplace's equation in 3 dimensions.
Associated Electrical Industries Research Laboratory, Aldermaston, Berks.	Two resistance-network analogues for the solution of the Laplace and Poisson equations in two dimensions. There is also a subsidiary apparatus which can be used in conjunction with these machines for solving heat transfer problems under transient conditions.
University College, Dundee.	Prototype computer for the solution of ordinary and partial differential equations by relaxation methods. Computing carried out by a network of DC. amplifiers connected by resistances and the sequence of operations is controlled by uniselector switches. Results displayed on cathode-ray tube.
University Mathematical Laboratory, Free School Lane, Cambridge.	Simultaneous equation solver. Will solve sets of up to 10 simultaneous linear equations.

I. CONVERSION OF DATA

Location	Machine
Nautical Almanac Office, Herstmonceux Castle, Nr. Hailsham, Sussex.	IBM. card controlled typewriter. This machine is designed to type copy for mathematical tables in a form suitable for direct reproduction by photography. It is extremely flexible and the results compare reasonably well with letter-press printing.
British Tabulating Machine Co.,Ltd., 17, Park Lane, London, W.1.	(a) For converting data on teleprinter tape to Hollerith cards. (b) For converting data on Hollerith cards to teleprinter tape. NB. The code used on the tape is the normal teleprinter code and these machines cannot be adjusted to read or punch other codes.
National Physical Laboratory, Teddington, Middlesex.	Equipment for enabling information on Powers-Samas 65 column cards to be transferred to Hollerith 80 column cards by means of the reproducer.
Royal Aircraft Establishment, S. Farnborough, Hants.	Equipment designed by R.A.E. for converting analogue quantities in the form of shaft rotations to digital form. A large number of these units are being made, mainly for use in recording data from wind-tunnel experiments. Each unit records one digit and a number of these units can be connected to give the required number of digits. The results can be printed and/or punched on Hollerith cards.

APPENDIX III

The Co-ordination of Ministry of Supply requirements for computing services and equipment

CS(M) Instruction No. 73 and CS(A) Notice to Branches No. 276

DWR(D) will in future co-ordinate requirements for computation services and computing equipment (other than conventional hand or electric desk machines). He will, for that purpose, be responsible to the Chief Scientist. DWR(D) will keep requirements under review, and will, if necessary, formulate proposals for setting up central facilities in the Department.

He will be prepared to advise Establishments and Directorates on the following:-

a) on computing equipment available or under construction in the Department and elsewhere;

b) on computing services;

c) on sources of expert advice on computational problems.

Establishments needing computing services or equipment should, if possible, use facilities already available in the Department.

Requisitions for expenditure on extramural services or new equipment (except conventional desk machines) should be submitted for financial approval through DWR(D), supported by evidence that Departmental facilities existing or on order, cannot be used to meet the requirement.

[dstl]

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AD#: AD020256

Date of Search: 9 July 2008

Record Summary: SUPP 27/6
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Former reference (Department) WR(D)13/53
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